CHAPTER 4.—DUST CONTROL IN STONE MINES

By Fred N. Kissell, Ph.D.,[1] and Gregory J. Chekan[2]

In This Chapter

- ✓ Drilling, blasting, and crushers
- ✓ Diesel particulate
- ✓ Enclosed cabs
- ✓ Ventilation with jet fans
- ✓ Stopping construction methods
- ✓ Propeller fans as main fans

This chapter explains how to control dust in large-entry stone mines, including both silica dust and diesel particulate. Most stone mines are limestone mines, but a substantial minority are marble, sandstone, and granite mines. These mines differ from most others in that entry widths are 30 ft or more and entry heights are 25 ft or more. Such mines, developed with room-and-pillar methods, have large open areas that can make ventilation and dust control more difficult.

Because of the difficulty of ventilating stone mines, improved ventilation is a major focal point of this chapter. However, the chapter also covers the control of dust from drills, blasting, and crushers. Another part of the chapter covers enclosed cabs, an effective dust control technique for some workers.

BACKGROUND

The major dust compliance problem in stone mines is caused by silica (quartz) in the rock. Mines in high-silica rock, 8% or more, are far more likely to have a dust problem than those where there is less silica. Geographically, the limestone in the Northeastern and South Central United States has higher silica than the rest of the country.

Chekan and Colinet [2002] have analyzed Mine Safety and Health Administration (MSHA) dust sampling results [MSHA 2001] from the stone industry. They have concluded that, on average across the United States, the workers exposed to the highest dust concentrations are rotary drill operators, front-end loader operators, truck drivers, and crusher operators. However, there are many regional differences. Also, occupations that work outside of cabs, such as blasters, roof bolters, and laborers, can be exposed to high dust levels.

---

[1]Research physical scientist.
[2]Mining engineer.
Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

CONTROL OF DUST FROM DRILLS, BLASTING, AND CRUSHERS

Drills, blasting, and crushers produce the most dust in stone mines. Drill dust can usually be controlled by proper maintenance of the water supply system. Blasting dust is controlled by firing off-shift. Crusher dust, a more difficult problem, is usually managed (with varying success) by ventilation and water sprays.

Control of drill dust. Drill dust is suppressed by water injected through the drill steel, a common practice for many years [ILO 1965]. Usually, respirable dust is reduced by 95% or better [MSA Research Corp. 1974]. However, this does not prevent dust from entering the air during the initial collaring period as the drill hole is started. Various means have been tried to prevent the escape of dust during collaring. These range from simple handheld sprays to elaborate types of suction traps around the end of the drill steel. None of these are very efficient.

Drills powered by compressed air are much less common than in the past, eliminating the dust problems associated with their use. For example, if some of the compressed air operating the drill leaks into the front head of the drill and escapes down the drill steel, it will cause dry drilling and carry dust out of the hole. Compressed air escaping through the front head release ports will atomize some of the water in the front head. This atomized water evaporates rapidly and, if the water is dirty, many dust particles will remain in the air [Sandys and Quilliam 1982].

MSA Research Corp. [1974] has listed the factors that can lead to high dust levels on drills. Many result from lack of proper maintenance. These are failure to use water, inadequate quantities of water, plugged water holes in the drill bit, dull drill bits, and dry collaring.

Control of blasting dust. Control of blasting dust is described in more detail in chapter 6, the chapter on hard-rock mines. Water is used to spray the blast area beforehand. Ventilation is used to exhaust fumes and dust via an untraveled return and between shifts. In most cases, the faces are shot during an off-shift, so no workers are in the mine at the time of the blasts. Studies have shown [Chekan and Colinet 2002] that in stone mines the retention time of the dust is usually less than 2 hr. If ambient levels of silica dust are high after this period or if workers are exposed to an excessive amount of dust from blasting when they reenter the mine, it usually indicates that the ventilation needs to be improved.

Control of dust from crushers. Dust from crushers is controlled by water sprays and local exhaust ventilation from the crusher enclosure. The amount of water needed to do the job is hard to specify. It depends on the type of material crushed and the degree to which water will cause downstream handling problems. If the rock is dry, a starting point is to add a water quantity equivalent to 1% of the weight of the material being crushed [Quilliam 1974]. The nozzle pressure of sprays at the grizzly and crusher jaw should be below 60 psi to avoid stirring the dust cloud and reducing the capture efficiency of the ventilation system.[3]

The amount of air required for dust control depends on how much the crusher can be enclosed. Enough air should be exhausted from a plenum under the crusher to produce a strong indraft at the jaw, grizzly, and any other openings around the crusher. The required airflow is usually large. For example, Rodgers et al. [1978] have described how dust from a 5-ft cone crusher was reduced by using a 75,000-cfm[4] exhaust ventilation system and a control booth for the operators.[5] Yourt [1969] has given a comprehensive set of design principles for dust control at crushing and screening operations.

Crushers need lots of air and lots of water because they break lots of rock.

In stone mines, dust that escapes the crusher is hard to contain because of the large cross-sectional area of the entries. Figure 4-1 shows a conceptual approach to controlling crusher dust in a limestone mine. The crusher is located in a crosscut that has been benched to facilitate dumping from trucks. The crusher operator is located in an enclosed booth that is pressurized with filtered air. The crosscut is divided by a stopping (or leak-tight curtain) that essentially puts the crusher and dump point in a stub heading. Air is exhausted from a plenum under the crusher to create an indraft at the crusher jaws. It is then directed through the stopping. Dust in this air can be removed with a baghouse or directed into the return.

Directing air through the stopping creates an inward air movement in the travelway. Because of this inward air movement, dust that escapes the crusher is more likely to stay confined within the stub heading and not escape into the rest of the mine. If the air velocity in the travelway is not high enough to confine the dust, a "half-curtain" approach might be helpful. Installing a half-curtain in the travelway reduces the cross-sectional area and raises the air velocity. The higher air velocity provides better dust confinement.[6]

The arrangement shown in figure 4-1 has the air doing double duty. It first confines dust in the crusher, then in the travelway. Whether all of this is necessary will depend on the circumstances in each individual mine. An enclosed operator booth alone may be adequate. However, it is

---

[3]Chapter 1, the dust control methods chapter, has a more comprehensive discussion on why high spray pressures should be avoided most of the time.

[4]Large air quantities may be required because falling rock induces its own airflow. Pring [1940] investigated the amount of air required to produce an indraft in surge bins at crusher installations. About 35,000 cfm was required at a large crusher installation.

[5]If large (80% or more) dust reductions are sought for workers near a crusher, the most practical way to achieve this is to provide an enclosed and pressurized control booth supplied with filtered air.

[6]The half-curtain is described more fully in chapter 2 on continuous miner dust control and chapter 1 on dust control methods.

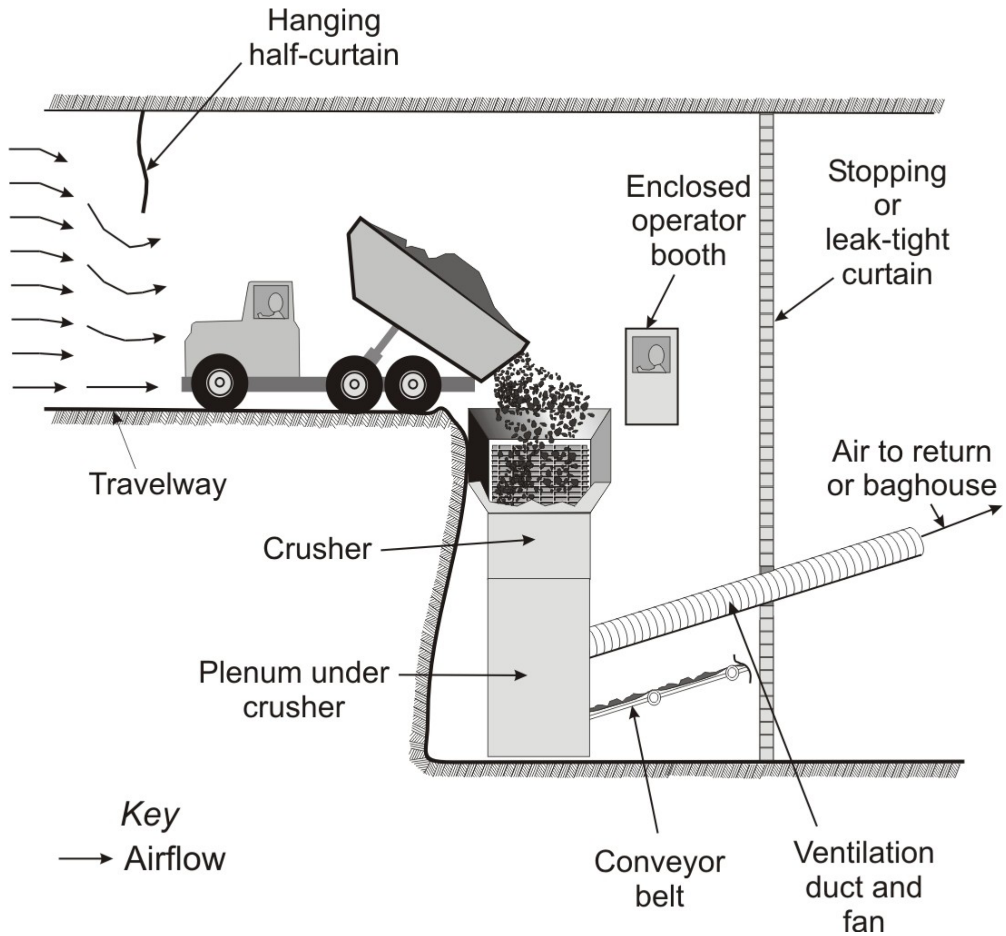

Figure 4-1.—Conceptual approach to controlling crusher dust in a stone mine.

hard to reliably get better than a 90% dust reduction in such booths under real mining conditions, so additional measures to reduce dust may be required.

CONTROL OF DIESEL PARTICULATE

Diesel particulate control is included in this chapter because new MSHA diesel rules may require upgrades to stone mine ventilation systems and diesel equipment. A detailed but readable review of diesel particulate controls has been written by Schakenberg and Bugarski [2002]. Essentially, the technology selected depends on how much the particulate must be reduced. Moderate particulate reductions may be obtained by better engine maintenance, engine derating, biodiesel fuel, fuel-water emulsions, and oxidation catalysts in conjunction with low-sulfur fuels. Large particulate reductions (80% or better) can be obtained with ceramic particulate filters on the engine tailpipe. Also, new low-emissions engines are available. These new engines can lower the particulate level as much as 75% if the existing engine has an old design.

Some reduction in diesel particulate levels can be achieved by running haulage trucks in return airways. However, since other equipment in the mine is also powered with diesel engines, the benefits of return haulage may be minimal. In many mines, the haulage truck horsepower is only a fraction of the installed diesel horsepower in the mine.

Reduction in diesel particulate can be obtained with improvements in the ventilation, as described in later sections on jet fans and stoppings. Head [2001a,b,c] recently wrote three helpful articles on better ventilation and reducing diesel emissions in stone mines.

USING ENCLOSED CABS TO CONTROL SILICA DUST AND DIESEL ARTICULATE

Cabs can reduce dust *if* their dust control systems are properly designed and maintained. Don't expect a dust reduction over 75%, though. There is more information on enclosed cabs in chapter 5, the surface mining chapter.

A high proportion of stone mine workers exposed to high dust levels can be protected with enclosed cabs or control booths. Haulage trucks in stone mines are often equipped with cabs. These cabs, if properly designed and maintained, can greatly lower the dust exposure of the truck drivers.

Impact of retrofitting. Chekan and Colinet [2002] recently measured the efficiency of an enclosed cab on a 27-year-old haulage truck in a limestone mine. In this study, the cab was originally equipped with a heating and air-conditioning unit that did not filter the intake air or pressurize the cab. Dust level measurements showed that its overall efficiency in reducing respirable silica dust was only 33%. The cab was then sealed and retrofitted with a new heating and air-conditioning unit that filtered the air and slightly[7] pressurized the cab. A new set of dust measurements gave an overall efficiency of 75% for respirable silica dust. This 75% overall efficiency figure was in line with dust efficiency results obtained with newer trucks.[8]

Cab filtration systems. Cab filtration systems can also trap diesel particulate if they are designed with this goal in mind. In underground stone mines, the level of diesel particulate is usually much higher than that found at surface mines, so the filtration of diesel particulate becomes an important consideration. Diesel particulate is much smaller in size than respirable mineral dusts, such as silica dust. So, if this diesel particulate is to be trapped by the cab filtration system, the filter must be much finer than that normally used to trap respirable dust. These

[7]To a pressure of 0.01 in w.g.

[8]These figures represent the overall cab efficiency, which is calculated from the inside and outside dust concentration values. Usually the filters have much higher efficiency values. However, leakage of dust into the cab and dust sources in the cab (such as dirty boots) cause the overall efficiency to be lower.

finer filters, usually designated as HEPA filters, have a higher pressure drop and require a more powerful fan.[9] They also require more frequent cleaning or replacement.

Efficiency to expect. When considering the use of cabs, it is important to recognize that the 75% efficiency figure cited above is a typical efficiency value for a relatively new cab with an average level of maintenance. Higher efficiency values can be obtained, but they are the exception rather than the rule. A sustained efficiency over 75% is hard to achieve under realistic underground mining conditions. The main reasons for this include poor or aging seals on the cab, the operator opening the cab door for work-related tasks, and the operator bringing dirt into the cab without performing a regular cleaning of the interior.

FACE AREA VENTILATION WITH JET FANS

Jet fans can aid stone mine ventilation if these guidelines for their use are closely followed.

A jet fan is a freestanding fan designed to induce additional air movement through a mine airway. Typically, no ductwork is attached to the fan, and the high-velocity[10] exhaust jet from the fan entrains additional air from around the fan and pushes it forward. Usually jet fans do not outperform those fans with attached ductwork. However, for ductwork to be effective it must be extended close to the working face where it is subject to blast damage. Jet fans are located farther away and can always be temporarily moved around a corner to avoid the direct path of a blast.

Jet fans have two applications. They are used to ventilate a straight single heading provided it is not too long, and they are used to ventilate a portion of the mine a few crosscuts away from the main pathway of fresh air. Jet fans cannot be used to ventilate an entire mine or even to move air more than a few crosscuts.

Jet fan ventilation of single headings. Figure 4-2 shows a jet fan placed to ventilate a straight single heading. It is placed at the entrance of the heading on the intake air side. It must be close to the rib, pointed straight ahead, and with the inlet extended slightly into the crosscut. Performance inevitably suffers when other locations are used. Keeping the fan within a foot or two of the rib ensures that the jet expands only on one side, increasing its penetration. Extending the inlet into the crosscut reduces recirculation.

Several studies have measured the performance of vane-axial fans at single headings like that shown in figure 4-2. Matta et al. [1978] used a 20,000-cfm fan to ventilate a heading 28 ft wide by 165 ft long. The height ranged from 17 ft at the crosscut to 9 ft at the face. Tracer gas tests

---

[9]MSHA recommends that HEPA filters always be used.
[10]4,000 to 9,000 ft/min or more.

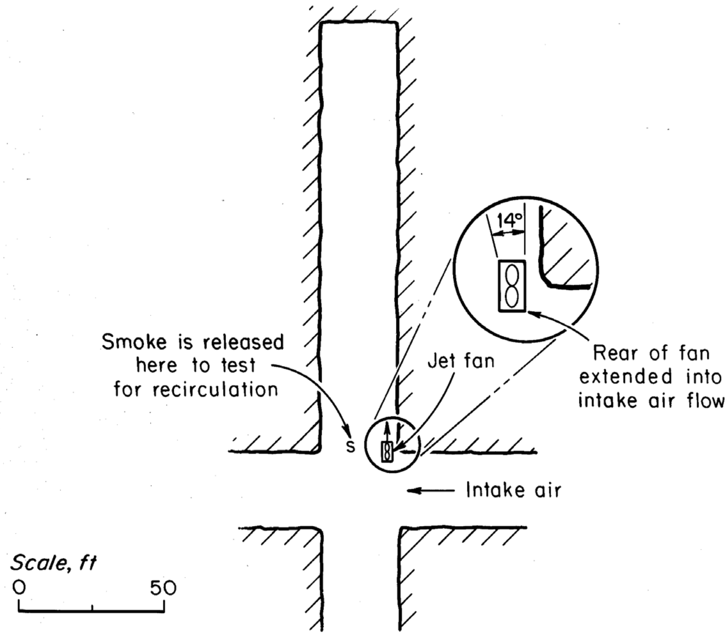

Figure 4-2.—Jet fan ventilating a single straight heading.

showed that 5,000 cfm of fresh air was reaching the face at 150 ft. A smaller 12,000-cfm fan with a 3-ft outlet nozzle pushed 6,000 cfm of fresh air to the face, and a 10,000-cfm compressed air-powered venturi air mover gave 3,500 cfm of fresh air to the face. The airflow in the crosscut was 57,000 cfm.

Matta et al. got better results when the fan had a nozzle attached. Lewtas [1980] obtained similar findings. Lewtas achieved the best air jet penetration when the nozzle was a truncated cone attached to a 1-ft-long straight section at the outlet. The sides of the cone were sloped at 18º from the axis; the ratio of the outlet diameter to the fan diameter was 0.68.

Brechtel et al. [1985] tested a jet fan in a larger heading, 55 ft wide by 30 ft high by 320 ft long. An 88,000-cfm jet fan was surprisingly effective, with 66,000 cfm of fresh air reaching the face, according to the tracer gas dilution tests. Airflow in the crosscut was 124,000 cfm.

Dunn et al. [1983a] tested jet fans in two different sizes of headings. Both were wide relative to their depth, probably the main factor leading to the high ventilation efficiencies. For example, in a heading of medium cross-section, 45 ft wide by 21 ft high by 115 ft long, a 7,000-cfm fan inclined up at 10º forced 6,700 cfm of fresh air to the face. There was 14,000 cfm in the cross-cut. In another heading with a large cross-section, 52 ft wide by 38 ft high by 150 ft long, a 14,000-cfm jet fan inclined upwards at 12º forced all of the 14,000 of fresh air to the face. The baseline ventilation with no fan was 4,500 cfm. A larger fan performed no better because only 15,000 cfm of fresh air was available in the crosscut.

Table 4-1 shows the results of all of the large-entry tests. The face ventilation effectiveness is the fresh air delivered to the face divided by the fan quantity, expressed as a percentage.

Table 4-1.—Results of jet fan studies

Researcher	Cross-sectional area, ft^2	Length, ft	Area-to-length ratio	Fan size, cfm	Face ventilation effectiveness, %
Matta et al. [1978]	476-252	165	~2:1	20,000	30
Matta et al. [1978]	476-252	165	~2:1	12,000 with nozzle	50
Matta et al. [1978]	476-252	165	~2:1	10,000, venturi	35
Brechtel et al. [1985]	1,650	320	5:1	88,000	75
Dunn et al. [1983a]	945	115	8:1	7,000, up 10º	96
Dunn et al. [1983a]	1,976	150	13:1	14,000, up 12º	100

Overall, these results show that jet fans can work reasonably well in a dead heading if the heading is large enough, the fan is properly located, and enough fresh air is provided to the fan inlet. The best results were obtained when the heading area to length ratio was high. A nozzle should be used to improve the jet penetration. Also, it may help to angle the fan upwards by 10º, per the findings by Dunn et al. [1983a].

Jet fans in headings should always be tested for recirculation by releasing smoke at location S in figure 4-2 and observing whether any travels back to the fan inlet. If recirculation to the fan inlet is present, it may help to attach a short length of ventilation duct to the inlet and then extend the other end of the duct upwind in the crosscut.

Jet fan ventilation of multiple headings a few crosscuts away from fresh air pathway. Jet fans have great potential for moving air short distances. However, ensuring an adequate quantity of fresh air can be difficult. Figure 4-3 shows a jet fan placed in the center of an airway and indicates how the air jet spreads as it moves away from the fan. This jet spreading results from the entrainment of the air next to the jet, and the amount of air entrained can be surprisingly high—

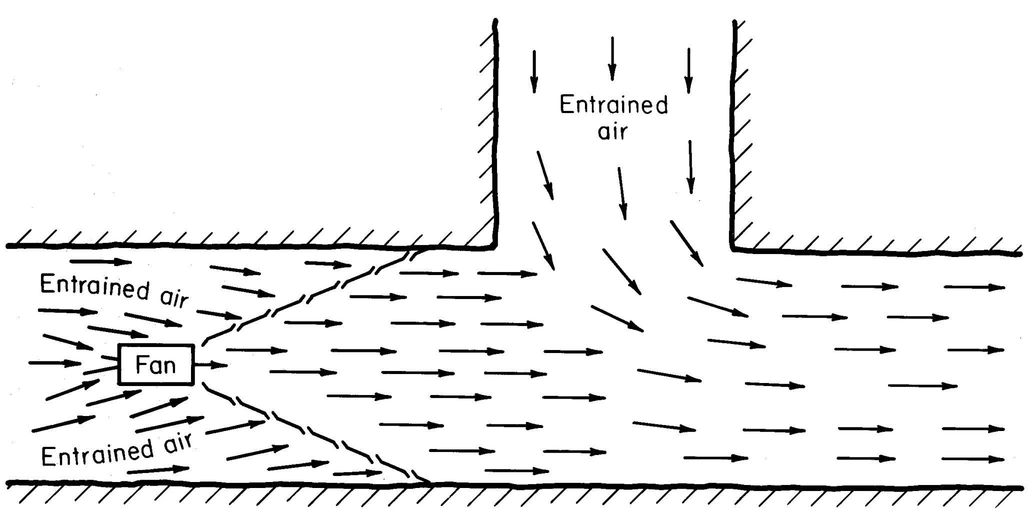

Figure 4-3.—Jet fan entrainment of mine air.

9 to 15 times the air quantity passing through the fan [Dunn et al. 1983b]. Air can also be entrained from crosscuts ahead of the fan, as shown in figure 4-3. Unfortunately, much of the entrained air is contaminated air that is recirculated back from the face, not fresh air.

Fresh air and recirculation. The challenge when using jet fan ventilation is how to place the fan to maximize the amount of fresh air. Having some recirculated air is not necessarily a problem. Studies have shown that recirculated air becomes a problem only when it is substituted for fresh air rather than added to a fixed quantity of fresh air [Kissell and Bielicki 1975].

As an example of how recirculated air can substitute for fresh air, figure 4-4 shows a portion of a mine a few crosscuts away from a fresh air pathway. Without a jet fan in operation, the mine air circulation in this part of the mine was directly from location 1 to location 2. A 14,000-cfm jet fan was placed close to a pillar at location A and directed toward the face area [Dunn et al. 1983a]. In this location, the fan worked well since the air movement it generated brought an average of 10,000 cfm of fresh air to faces FA through FD. Location B, close to the opposite side of the pillar, was almost as effective in relation to fan placement.

Experimenting with other locations, when the fan was placed at either of the two locations close to the adjacent pillar, marked X and Y, fresh air delivery was cut by 40% and 80%, respectively. Even though the distance from A and B is less than 100 ft, X and Y are too far from the intake air source, permitting recirculated air to return on both sides of the fan and diminish the fresh air. However, for fan locations A and B, the recirculated air returns only on one side, the left side, since the rib on the right side serves as a natural barrier. Figure 4-5 shows the airflows obtained with the jet fan in operation at location A. The airflow directions show that all of the fresh air was being directed toward the working faces, even though there was also a large amount of recirculated air.

Important conclusions from this work done by Dunn et al. were that fans must be placed in the incoming fresh airflow. In the larger airways, it helped to angle the fan upwards by 10º. Also, under this work it was concluded that larger-capacity fans ventilate more effectively if enough intake fresh air is available.

If you want to move air for distances greater than those shown in figure 4-5, forget about jet fans. Use ventilation ductwork or build stoppings.

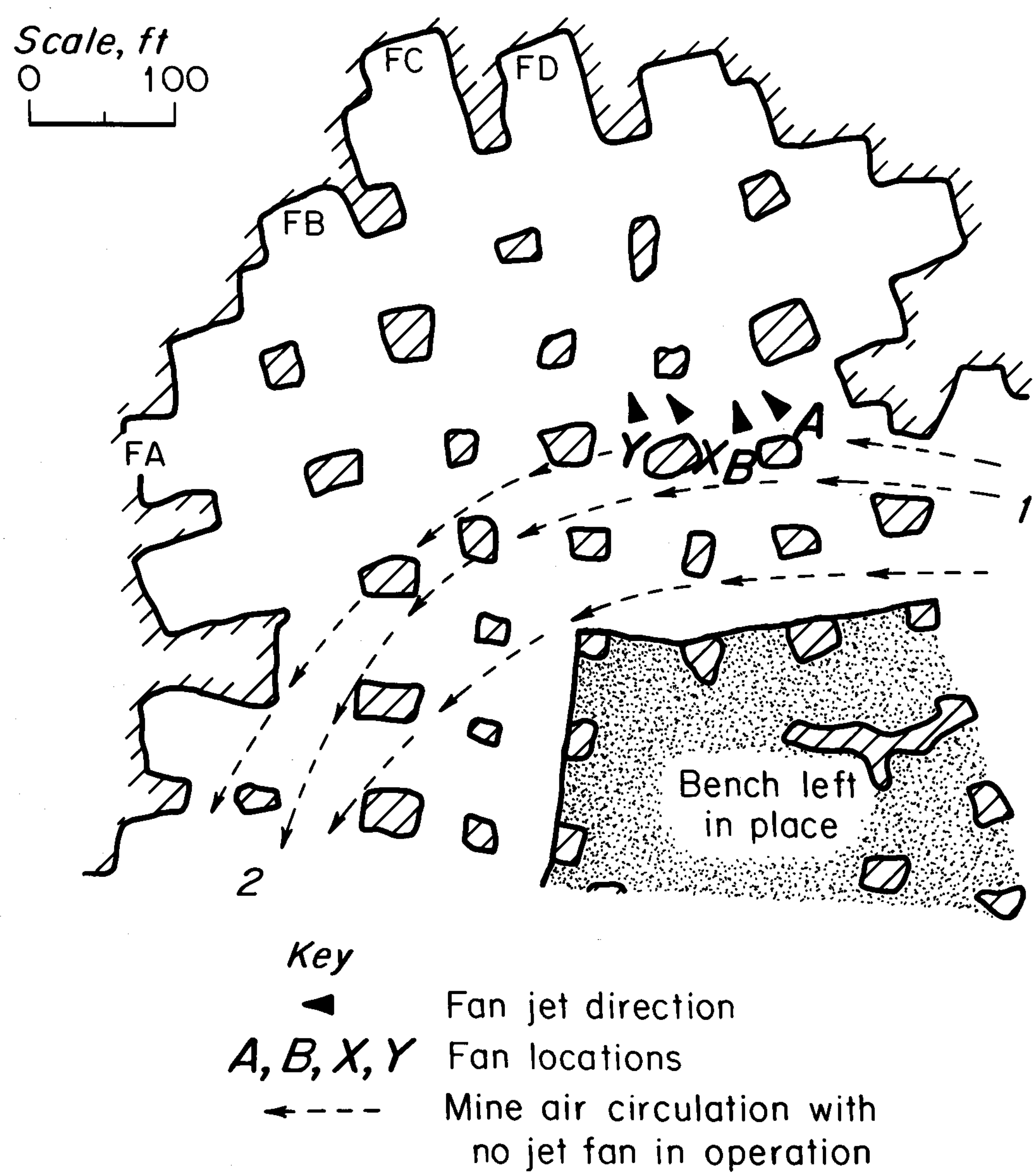

Figure 4-4.—Multiple headings a few crosscuts away from a fresh air pathway.

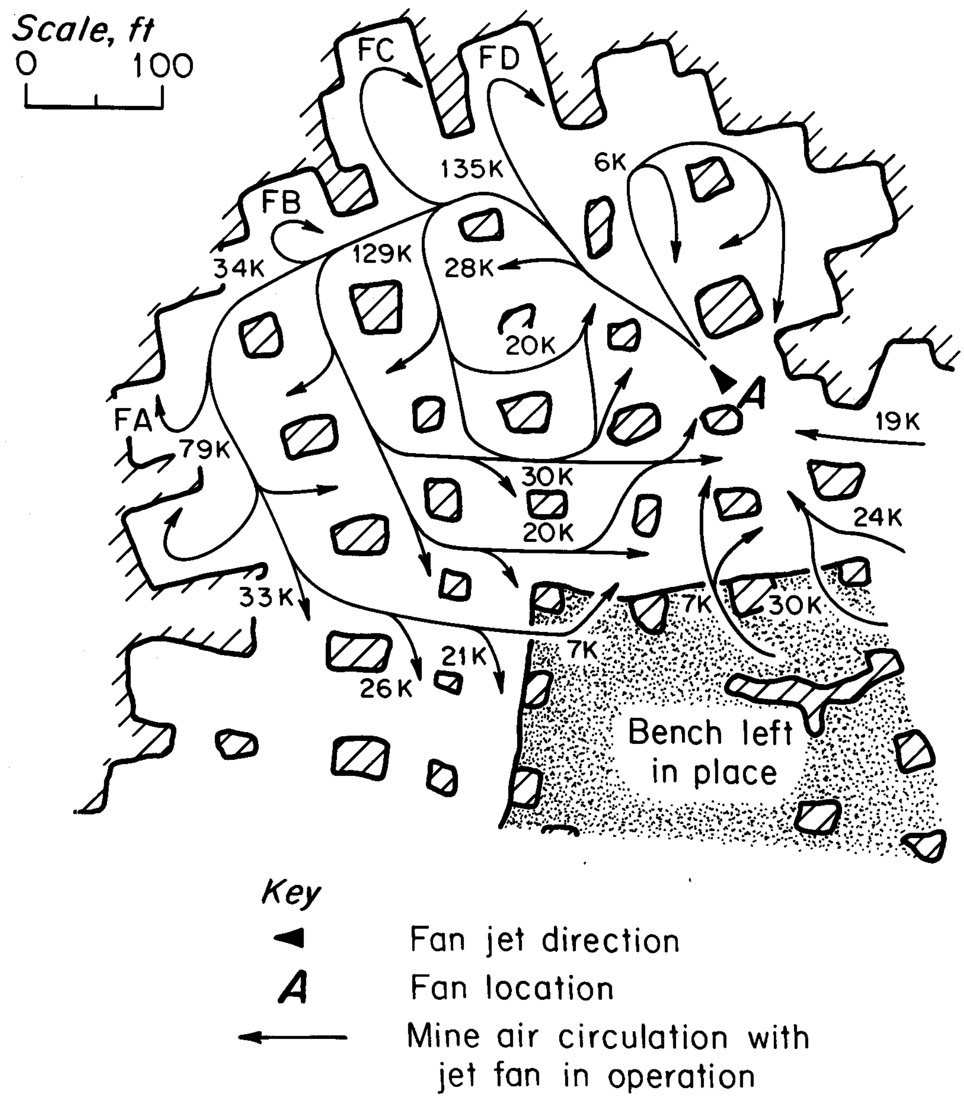

Figure 4-5.—Airflows obtained with jet fan in operation.

METHODS OF STOPPING CONSTRUCTION

In mines with large entries, stopping construction is a major task. Fortunately, some innovative stopping designs are available.

Well-built low-leakage stoppings are essential for good mine ventilation. Adam et al. [1986] have experimented with alternative stopping designs for large mine openings. The work was undertaken to develop construction techniques and cost data and to measure leakage rates on full-scale structures in an oil shale mine where the entries were 30 ft high by 55 ft wide. Six full-size stoppings and one overcast were built. Leakage was measured before and after a full-scale face blast. The lessons learned are applicable to today's stone mines.

Muckpile stoppings. Muckpile stoppings elicited the most interest from mine operators. These were simply piles of waste material stacked in crosscuts. However, the air leakage from this type of stopping was far too high, possibly because there were not many fines in the waste. Adam et al.'s recommendation for achieving less leakage was to use a "pipe and sheeting" stopping in main entries and a "brattice and wire-mesh" stopping in individual panels.

Pipe and sheeting stoppings. The pipe and sheeting stopping is formed on 5- and 6-inch telescoping, 1/4-inch wall, square-section steel tubes. These tubes were set into shallow holes that had been drilled into the floor on 7.5-ft centers. At the roof, directly above each floor hole, an 8-in-long, 3-in by 3-in by 3/8-in piece of angle iron was attached using a 2-ft resin roof bolt. The top of each telescoping member was welded to a roof angle. The connection between the two tubes was also welded. Corrugated metal sheets were then fastened to the vertical support members on the high-pressure side using self-drilling screws. All sheeting seams and the stopping perimeter were then sealed with a polyurethane foam.

Brattice and wire mesh stopping. To build a brattice and wire-mesh stopping, short pieces of threaded rod, 1/2-inch in diameter by 4 inches long, were first welded every 2 ft to a section of angle iron 4 inches by 4 inches by 1/4 inch by 10 ft long. This angle iron was then bolted to the roof and floor using 2-ft resin bolts on 3-ft centers. Next, a wire fencing layer was placed across the opening, and each panel of fence was attached to the angle base on the roof and floor. Then, brattice with velcro strips sewn down the vertical edges were attached to the angle bars on the high-pressure side. The velcro seams were then fastened to create a sealed wall of brattice. Following the brattice installation, a second layer of wire fence was attached across the drift in a fashion similar to the first. The two layers of fence sandwiching the brattice were then securely fastened to the threaded rod with roof bolt plates, washers, and nuts. Finally, all velcro seams and the stopping perimeter were sealed with polyethylene foam.

Blast relief with damage-resistant brattice. Close to the face, some blast relief is needed. A stopping of "damage-resistant brattice" (figure 4-6) can be used [Thimons et al. 1978]. Damage-resistant brattice consists of vertical brattice panels joined by velcro seals. To form a stopping of damage-resistant brattice, a strip of velcro is sewn to each edge of a roll of brattice cloth on the same side of the fabric. The end of the roll is wrapped around a wooden 2 by 4 that is slightly shorter than the width of the roll. The 2 by 4 is then bolted to the roof, with the brattice hung down to the floor. The operation is repeated to extend a curtain all the way across the entry. Adjacent cloth panels are sealed to each other with the velcro. The velcro strips are sewn to the same side of adjacent panels so that they separate by peeling rather than shearing. Next, other wood 2 by 4s are bolted to the ribs. Velcro is then stapled on and the adjacent brattice curtain attached. Blast forces can split the seams between the panels and at the ribs, but they can easily be reattached. When blast forces are no longer a concern at that location, adjacent panels can be stapled together. Also, wire mesh can be placed on either side to make a more pressure-resistant brattice and wire-mesh stopping.

Table 4-2 shows the leakage and cost of the three types of stoppings, along with two types of muckpile stoppings. With the exception of the muckpile stoppings, the leakage values were reasonable. However, the costs were high because there were such large entries to be sealed.

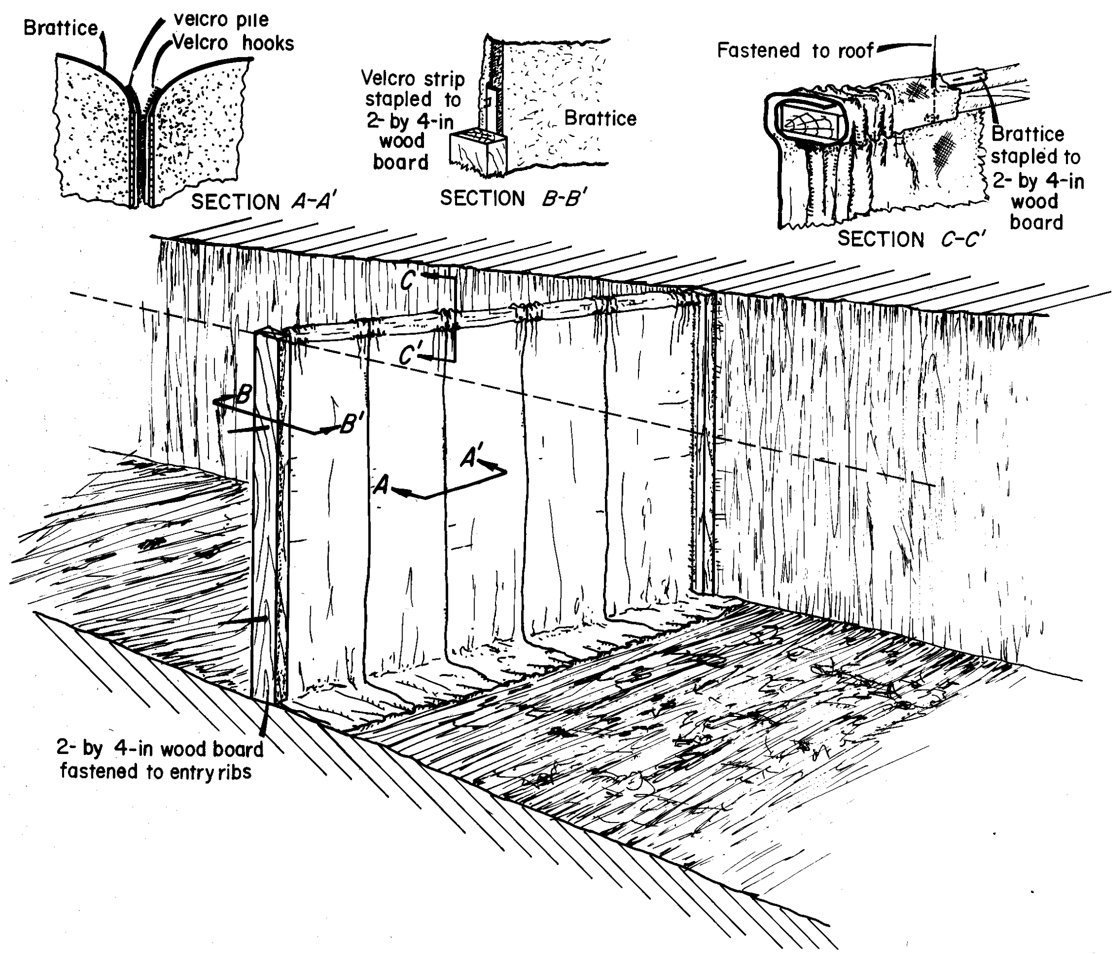

Figure 4-6.—Stopping built from damage-resistant brattice.

Table 4-2.—Cost and leakage of five types of stone mine stoppings

Type of stopping	Cost (2001 prices)	Leakage in cfm/1,000 ft^2 at 0.10 in w.g.
Pipe and sheeting	$15,000	80
Brattice and wire-mesh	$7,000	160
Damage-resistant brattice	$2,400	200 (before blast)
Muckpile stopping	$5,800	5,100
Muckpile and brattice stopping	$2,400	2,200

Because of the high stopping costs, Adam et al. [1986] also considered a wide variety of alternatives in the room-and-pillar layout to reduce the number and size of stoppings required. Typical alternatives were longer pillars along a stopping line, development of bleeder entries, ventilation from adjacent panels, and reduced-width "hourglass" crosscuts that were widened on the retreat benching operation. These alternatives were then weighed in a cost-efficiency model that considered the volume mined per unit stopping area, haulage distance, and equipment tram distance. Adam et al. concluded that stopping size and cost could be reduced by any of several cost-effective alternatives.

PROPELLER FANS AS MAIN FANS

Save money by using propeller fans.

Improved dust control in many stone mines will require installing new main fans. Many stone mines have access exclusively through parallel drift entries, that is, they have no shafts or slopes. Because the pressure drop associated with moving air through large entries is low, these mines may be able use low-pressure, high-volume propeller fans as main fans. Grau et al. [2002] have measured air quantities and pressure drops in two stone mines having only parallel drift entries and no shafts or slopes. Results are shown in table 4-3.

Table 4-3.—Pressure drop in stone mine airways

Mine	Airway length, ft	Air quantity, cfm	Fan pressure, in w.g.
A	2,400	350,000	0.12
B	7,000	280,000	0.06

These air quantities and fan pressures are well within the reach of large-diameter (10- to 12-ft) propeller fans. Such fans will be much less expensive to purchase and operate as main fans than vane-axial fans delivering the same airflow and pressure.

REFERENCES

Adam ME, Brechtel CE, Agapito JFT [1986]. Improved stopping, door, and overcast construction for oil shale mines. J. F. T. Agapito & Associates, Inc. U.S. Bureau of Mines contract No. J0145020. NTIS No. PB87-174918.

Brechtel CE, Adam ME, Agapito JFT [1985]. Development of effective face ventilation systems for oil shale mining. J. F. T. Agapito & Associates, Inc. U.S. Bureau of Mines contract No. H0134033. NTIS No. PB86-159829.

Chekan GJ, Colinet JF [2002]. Silica dust sources in underground limestone mines. In: Proceedings of the 33rd Annual Institute on Mining Health, Safety and Research (Roanoke, VA, Aug. 11-13, 2002).

Dunn MF, Kendorski FS, Rahim MO, Mukherjee A [1983a]. Testing jet fans in metal/nonmetal mines with large cross-sectional airways. Engineers International, Inc. U.S. Bureau of Mines contract No. J0318015. NTIS No. PB84-196393

Dunn M, Kendorski F, Rahim MO, Volkwein J [1983b]. Auxiliary jet fans and how to get the most out of them for ventilating large room-and-pillar mines. Eng Min J *Dec*:31-34.

Grau RH III, Robertson SB, Mucho TP, Garcia F, Smith AC [2002]. NIOSH ventilation research addressing diesel emissions and other air quality issues in nonmetal mines. SME preprint 02-187. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc.

Head HJ [2001a]. Proper ventilation for underground stone mines. Aggregates Manager *Jan*: 20-22.

Head HJ [2001b]. Calculating UG mine ventilation fan requirements. Aggregates Manager *Apr*:17-19.

Head HJ [2001c]. Managing diesel emissions in underground mines. Aggregates Manager *Jun*:17-18.

ILO [1965]. Guide to the prevention and suppression of dust in mining, tunnelling, and quarrying. Geneva, Switzerland: World Health Organization, International Labour Office.

Kissell FN, Bielicki RJ [1975]. Methane buildup hazards caused by dust scrubber recirculation at coal mine working faces: a preliminary estimate. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 8015. NTIS No. PB-240 684/1/XAB.

Lewtas TA [1980]. Assessment of induction fan effectiveness. Foster-Miller Associates, Inc. U.S. Bureau of Mines contract No. J0387223. NTIS No. PB82-2359870.

Matta JE, Thimons ED, Kissell FN [1978]. Jet fan effectiveness as measured with SF_6 tracer gas. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 8310. NTIS No. PB-288 173/8/XAB.

MSA Research Corp. [1974]. Control of respirable dust in noncoal mines and ore processing mills – handbook. U.S. Bureau of Mines contract H0220030. NTIS No. PB 240 646.

MSHA [2001]. Sampling results from 1996 to 2000 from the metal/nonmetal mine inspection data (MNMID). Pittsburgh, PA: U.S. Department of Labor, Mine Safety and Health Administration, Pittsburgh Safety and Health Technology Center, Dust Division.

Pring RF [1940]. Dust control in large-scale ore concentrating operations. American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1225.

Quilliam JH [1974]. Sources and methods of control of dust. In: The ventilation of south African gold mines. Yeoville, Republic of South Africa: The Mine Ventilation Society of South Africa.

Rodgers SJ, Rankin RL, Marshall, MD [1978]. Improved dust control at chutes, dumps, transfer points, and crushers in noncoal mining operations. MSA Research Corp. U.S. Bureau of Mines contract No. H0230027. NTIS No. PB 297-422.

Sandys MPJ, Quilliam JH [1982]. Sources and methods of dust control. In: Environmental Engineering in South African Mines. Yeoville, Republic of South Africa: The Mine Ventilation Society of South Africa.

Schnakenberg GH Jr., Bugarski AD [2002]. Review of technology available to the underground mining industry for control of diesel emissions. Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2002-154, IC 9462.

Thimons ED, Matta JE, Kissell FN [1978]. Bureau of Mines damage-resistant brattice. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 8270. NTIS No. PB-278-607.

Yourt GR [1969]. Design principles for dust control at mine crushing and screening operations. Can Min J *90*(10):65-70.